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Inventory of forest biomass
left after logging
in western Canada

by

Le Fonds de recherches forestières
de l'Université Laval

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Authors: Jacques Bélanger
Jean-Marie Dumont
Gervais Bélanger

Available from:

Forest Engineering Research
Institute of Canada
143 Place Frontenac
Pointe Claire, Québec
H9R 4Z7

ENFOR Secretariat
Canadian Forestry Service
Department of the Environment
Ottawa, Ontario
K1A 0E7

PREFACE

This report is the result of the last phase of a study made in accordance with a mandate from the Forest Engineering Research Institute of Canada (FERIC), as part of the Canadian Forestry Service's Energy from the Forest (ENFOR) program.

Under the same agreement with the "Fonds de recherches forestières de l'Université Laval" (FRUL), an inventory was carried out in 1979 in some important forest types of Eastern Canada. The final report was presented to FERIC in March 1980, under the title: "Inventaire de la biomasse forestière résiduelle après coupe" (Inventory of forest biomass left after logging).

SUMMARY

Two forest stands located in the province of Alberta, Canada, one of white spruce and one of lodgepole pine, were inventoried for their residual forest biomass following tree-length logging.

In addition to estimating the quantity of fuel available for energy the study was also intended to compare the effectiveness of two sampling methods; the transect method and the weighing method.

The main results are as follows:

Lodgepole pine (weighing)	34.25 ODt/ha (oven-dry tons/hectare)
(transect)	32.21 ODt/ha
White spruce (transect)	40.93 ODt/ha

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INTRODUCTION

The last phase of a study to determine the amount of energy which can be generated by the residual forest biomass was conducted in Alberta, on the woodlands of St. Regis (Alberta) Ltd. This study took place in two major forest types, namely, the lodgepole pine and the white spruce types. In both cases the areas had been logged by tree length, the most widely used method in Canada.

The prime objective was to assess the amount of residues on the cutting areas. There was also an opportunity to apply and compare two methods for estimating the biomass of these residues.

FRUL favors the use of circular 0.04 ha sample plots and the weighing of residues by distinct categories. The transect method is another way of estimating biomass.

The lodgepole pine residues were estimated by both methods in a comparative study. For the spruce stand only the transect method was used.

1.0 GENERAL

1.1 Location of Study Area

The study area is located east of the Rockies near Hinton, about 70 kilometers north-east of Jasper. Its approximate latitude is 53° north and longitude 118° west.

1.2 Description of the Environment



According to Rowe's classification, the station under study is located in the interior subalpine forest region (SA.1) on the eastern slopes of the Rockies, at an approximate elevation ranging from 1500 to 2100 meters. The most common tree species encountered are Engelmann spruce, or hybrids of Engelmann spruce and white spruce, alpine fir, and lodgepole pine. Black spruce, white spruce and trembling aspen are also present.

In general soils are shallow and the horizons of the humo-ferric podzols are thin. The overall regional topography is mountainous.

2.0 METHODOLOGY

2.1 Weighing Method

The weighing method, used by FRUL for biomass inventory, is fully described in pages 18 to 23 of a first report entitled: "Inventory of forest biomass left after logging". Therefore, only a brief description of the method is given here.

Fifteen circular 0.04 ha sample plots were established in freshly logged areas. After outlining the plot boundary the residues were piled and weighed by the following categories:

- tops
- branches
- green stems
- dead stems

The average moisture content of samples collected at various levels in each category was determined in the laboratory. In this way the total dry weight of the residues was determined.

Field measurements included the height and diameter of residual trees and stumps (aerial section). Imperial measures were used for all measurements and conversion to the metric system was done during compilation.

2.2 Transect Method

2.2.1 Theory

This method was first applied by two scientists from New Zealand, W.G. Warren and P.F. Olsen.

The basis of their theory is the fact that all pieces do not have the same probability to be counted. The probability is dependent upon the orientation and length of the pieces in relation to the sampling line.

The following formula was used to calculate the volume of residues per acre:

$$\text{Vol/acre} = \frac{660 \alpha n}{I_c B} \quad (1)$$

α = factor varying with the size of pieces (average volume of pieces)

n = number of pieces crossed by the line

I_c = a factor based on the orientation of pieces in relation to the direction of the line

B = length of the line (in chains)

660 = conversion factor to cubic feet per acre

Factors α and I_c must be calculated in advance.

G.R. Bailey suggested in 1969 that I_c could be given a value of 0.637 radian if the transects were numerous enough, of equal length, and perpendicular to one another.

However, estimating α (average volume per piece) becomes more difficult if twigs and branches are added to the residues.

In 1967 C.E. Van Wagner made an interesting modification to the above formula (1). It is no longer necessary to measure the length of the pieces to calculate factor α .

Van Wagner considers that the longer the piece, the greater is the probability of a line crossing it. He suggests the following formula:

$$\text{Volume/area} = \frac{\pi^2 \sum d^2}{8.L} \quad (2)$$

d = diameter of pieces at the point of intersection

L = length of the transect

To obtain the weight/acre, the formula is:

$$\text{Weight/Acre} = \frac{11.65 s \sum d^2}{L} \quad (3)$$

s = specific gravity

d = diameter in inches

L = length in feet

The last two formulas have a marked advantage over the first one. It is no longer necessary to calculate the average volume of pieces (α). Residue volume is now a function of the diameter of the intersecting pieces.

In 1974 J.K. Brown suggested an inventory procedure using sampling lines of different lengths based on the respective diameter of the pieces.

The transect theory assumes that the pieces surveyed are lying horizontally. However, small diameter pieces tend to be an exception to this rule and this is why Brown applies correction factors to the Van Wagner formula. He adds to the formula (3) a first value allowing for the non-horizontal angles of the small diameter pieces. He also adds a correcting factor for the ground slope effect.

2.2.2 Description of the Method Used

The J.K. Brown method for estimating residues, as described in the "Handbook for inventorying downed woody material", was adopted for this study.

2.2.2.1 Number and length of the lines

On page 3 of his report, Brown has the following table (Table 1)*:

TABLE 1

SAMPLING AS A FUNCTION OF THE NATURE
AND SIZE OF PIECES

<u>Downed Material</u>	<u>Diameter of Debris (cm)</u>		
	<u>0-2.53</u>	<u>2.54-7.61</u>	<u>≥7.62</u>
	<u>sampling line (m)</u>		
Nonslash (naturally fallen material)	1.83	3.05-3.66	10.67-15.24
Discontinuous light slash	1.83	3.05-3.66	10.67-15.24
Continuous heavy slash	0.91	1.83	4.57- 7.62

Because the larger pieces greatly affect the volume and the weight of residues, it was decided to intensify the sampling for a greater accuracy. The level of precision can be improved by increasing either the number of sampling lines or the length of the line. The second option was adopted. (Table 2)

TABLE 2

LENGTH OF THE SAMPLING LINES

<u>Diameter of Pieces</u> (cm)	<u>Length of the Line</u> (m)
0-0.63	1.83
0.64-2.53	3.66
2.54-7.61	15.24
≥7.62	15.24

* All tables from Brown's report were converted to the International System of Units (S.I.).

Accuracy is also a function of the quantity of residue. The variance increases as the quantity of debris gets smaller and increasingly scattered, thus resulting in a loss of accuracy.

This was the reason for using the preceding sampling intensity. Given the number of sample points vs % of error from Brown's diagram (p. 21), the number of sampling lines was set at a minimum of 100.

2.2.2.2 Procedures

A - Lay-out of sample plots

Transect lines were laid out 22.86 m apart. Along each transect there was a starting point at every 15.24 m.

B - Sampling

- Identify the starting point of the sampling line, making sure the residues remain undisturbed.
- Determine the direction of sampling line. Angles included between 0° and 150°, in 30° sections, were determined at random.
- Lay the measuring tape parallel to the ground to mark the sampling line, as previously determined.
- Evaluate the slope to the nearest 10% along the sampling line.
- Count the pieces by the following classes:

0-0.63 cm
0.64-2.53 cm
2.54-7.61 cm

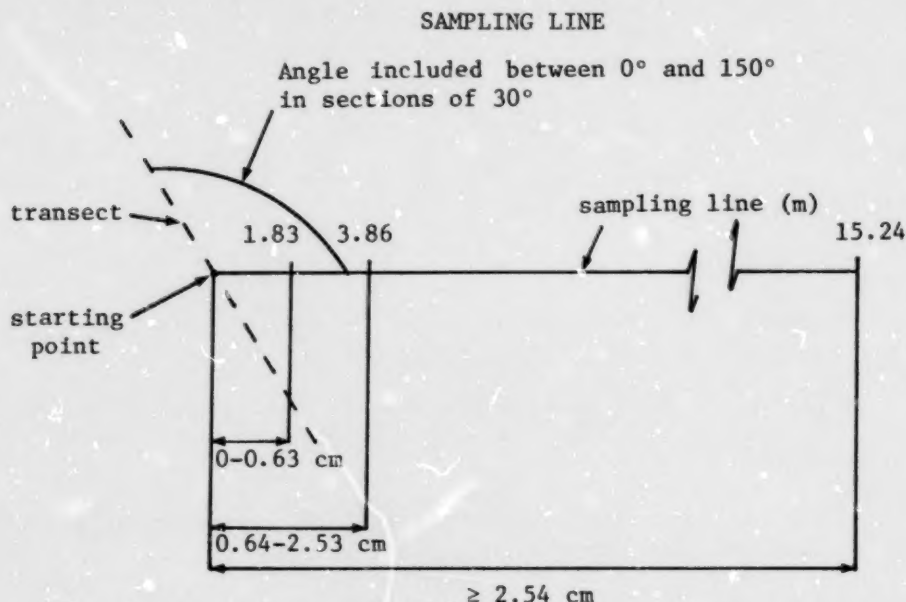
The diameter must be measured at the point of intersection. According to this method, the sample plot is in a vertical plane. Counting of the pieces must be taken in a vertical projection of the tape.

- Measure all pieces having a diameter greater than 7.61 cm. Record the length of these pieces. These measurements are taken along the full length of the line.
- By an ocular estimate give the proportions of the three most important tree species.

NOTE: Brown suggests measuring the depth of the litter layer and of the duff layer. These items were not included in this study.

In addition to the above, meteorological data for July were noted. They give maximum and minimum temperature, relative humidity, wind velocity and precipitation (appendix).

FIGURE 1



C - Rules for counting

- All pieces lying on the ground or intermingled with the pieces on the ground are counted regardless of their condition. The only exceptions are the pieces hanging from standing trees or shrubs.
- Branches and twigs in the litter or on top of it are counted when the point of intersection between the sampling line and the central axis of the piece does not lie in the duff.
- When the sampling plane crosses the end of a piece it is counted only if the point of intersection with the central axis of the piece is on the plane. If the point of intersection is exactly at the cross-point of the plane of intersection with the extremity of the central axis, only every second piece is counted.
- A piece is not counted when the sampling plane runs exactly along its central axis.
- Count every intersection for a curved piece.

- Count splinters and large pieces of wood. To obtain the diameter, or the diameter class, make a projection in the shape of a cylinder.
- Uprooted stumps and exposed roots are counted.
- Decayed or split open pieces may be reshaped as a cylinder. The diameter of the decay is thus smaller than the original diameter of the log.
- In counting, proceed from bottom to top. In practice the upper limit is 1.83 meters above the ground. This existence of an upper limit settles the question as to whether the piece is on the ground or not. According to the USDA Forest Service Northern Region, a tree is on the ground when the intersection of the line with the axis is below 1.83 meters from the ground. If not, the tree is considered as standing.

This becomes a very important distinction when the residues are heavy with residual standing trees entering the survey.

2.2.2.3 Calculations

The following formula gives the weight/area:

$$P(\text{tons/acre}) = \frac{11.64 \cdot d^2 \cdot \eta \cdot s \cdot a \cdot c}{N \cdot \ell} \quad (4)$$

d = (average diameter of the class)² (in²)

η = number of intersections

s = specific gravity

a = correction factor for non-horizontal piece angles

c = slope correction factor

N = number of sampling points

ℓ = length of the sampling line for each diameter class (ft)

11.64: Constant derived from the following transformation:

$$11.64 = \frac{\pi^2}{8} \cdot \frac{\text{in}^2}{144 \text{ in}^2} \cdot \frac{\ell \text{ ft}^2}{\text{ft}^3} \cdot \frac{62.4 \text{ lb}}{\text{ft}^3} \cdot \frac{\ell \text{ ton}}{2000 \text{ lb}} \cdot \frac{43560 \text{ ft}^2}{\text{acre}}$$

The volume is obtained by using the following formula:

$$V (\text{ft}^3/\text{acre}) = \frac{373.19 \cdot \eta \cdot d^2 \cdot a \cdot c}{N \cdot \ell} \quad (5)$$

$$373.19 = \frac{\pi^2/8 \times \text{in}^2 \times \text{ft}^2/144 \text{ in}^2 \times 43560 \text{ ft}^2/\text{acre}}{\text{ft}}$$

or else:

$$V \text{ (ft}^3\text{/acre)} = \frac{32.05 P}{s} \quad (6)$$

P = weight (tons/acre)

s = specific gravity

$$32.05 = \frac{373.19 P}{11.64 s}$$

The formulas stated above are used with the Imperial system.
With the S.I., the formula would be:

$$P(\text{tonnes/hectare}) = \frac{1.234 \cdot \eta \cdot d^2 \cdot s \cdot a \cdot c}{N \cdot \ell} \quad (7)$$

It must be remembered that formulas (4), (5) and (7) are used only when the pieces are less than 7.62 cm in diameter. When the real diameter is greater, ηd^2 is replaced by Σd^2 . Then, the formula will read as follows:

$$P \text{ (weight/acre)} = \frac{11.64 \cdot \Sigma d^2 \cdot s \cdot a \cdot c}{N \cdot \ell}$$

All parameters used in the preceeding equations, with the exception of η and ℓ , can be found in reference manuals or arrived at through experiments.

- The slope correction factor (c) is calculated with the following equation:

$$c = \sqrt{\ell + \left(\frac{\% \text{ slope}}{100} \right)^2}$$

These factors can be taken directly from Table 3 (Brown, p. 13).

TABLE 3

SLOPE CORRECTION FACTORS

<u>Slope</u>	<u>Factor</u>	<u>Slope</u>	<u>Factor</u>
0	1.00	60	1.17
10	1.00	70	1.22
20	1.02	80	1.28
30	1.04	90	1.35
40	1.08	100	1.41
50	1.12	110	1.49

- The correction factor for non-horizontal particle angles (a). These factors are found in Table 4, as suggested in Brown's study (p. 17).

TABLE 4

CORRECTION FACTORS FOR NON-HORIZONTAL PIECES

Diameter class (cm)	Species	Factor "a"	
		Fresh slash	One year old and older slash
0-0.64	PP	1.25	1.25
	others	1.40	1.15
0.64-2.54	PP	1.25	1.25
	others	1.13	1.13
2.54-7.62	PP	1.22	1.22
	others	1.10	1.10
≥7.62	all species	1.00	1.00

PP: Ponderosa pine (*Pinus ponderosa*)
 others: Douglas fir (*Pseudo-tsuga mensiesii*)
 Lodgepole pine (*Pinus contorta*)
 Engelmann spruce (*Picea engelmannii*)
 Western red cedar (*Thuja plicata*)
 Western Larch (*Larix occidentalis*)
 Grand fir (*Abies grandis*)

- Specific gravity

Brown recommends the use of specific gravity values available in standard sources (Wood Handbook). Average values can also be used, disregarding the species (Table 5). Specific gravity is given by diameter class for softwood species in general.

TABLE 5

SPECIFIC GRAVITY OF PIECES BY DIAMETER CLASS

Diameter class (cm)	Specific gravity
0-0.63	0.48
0.64-2.53	0.48
2.54-7.61	0.40
7.62+sound	0.40
7.62+decayed	0.30

However, for more accurate results, laboratory measurements were made to determine the specific gravity of the pieces by diameter class. The 0-2.53 cm class was not calculated due to the risk of error in such small pieces.

$$= (\text{average diameter of the class})^2 (d^2)$$

As stated by Brown in his study, d^2 can be obtained using the following formula:

$$d^2 = \frac{P_1 d_1^2 + P_2 d_2^2 + P_3 d_3^2}{P_1 + P_2 + P_3}$$

where P_1 , P_2 and P_3 represent the three main species, in the proportion found on the transect lines. Average diameters by diameter class for every species noted are subsequently entered in the formula. The average diameters are derived from Table 6 as suggested in Brown's study.

TABLE 6

AVERAGE DIAMETER BY DIAMETER CLASS
OF PIECES AND BY SPECIES

Diameter class (cm)	Natural residues		Logging residues	
	Forest Type	d^2 (cm ²)	Species	D^2 (cm ²)
0-0.63	PP	0.2206	PP, LP	0.1600
	LP	0.1297	L	0.0961
	S, DF, AF, C	0.0787	DF, GF, C, S	0.0787
	L	0.0961	Mixed	0.0974
	Mixed	0.0974		
0.64-2.53	LP	2.2194	PP, C	2.0452
	S, DF, AF, C	1.9613	DF, GF, LP, L, S	1.7935
	L, PP	1.5355	Mixed	1.8645
	Mixed	1.8645		
2.54-7.61	PP, AF	20.1290	LP	22.5806
	S, DF, C, LP	18.5161	DF, PP, GF	18.2580
	L	14.0000	L, C, S	14.8387
	Mixed	17.8064	Mixed	17.8064

PP: Ponderosa pine (*Pinus ponderosa*); LP: Lodgepole pine (*Pinus contorta*); S: Engelmann spruce (*Picea engelmannii*); DF: Douglas fir (*Pseudotsuga menziesii*); L: Western larch (*Larix occidentalis*); GF: Grand fir (*Abies grandis*); C: Western red cedar (*Thuja plicata*); AF: Alpine fir (*Abies lasiocarpa*).

It has been suggested by E. Heidersdorf, of FERIC, that the average diameter for a diameter class could be established by the following formula:

$$d^2 = \left[\left(\frac{\text{MAX} - \text{MIN}}{3} \right) + \text{MIN} \right]^2$$

MAX and MIN are the maximum and minimum values of the class range.

This formula was used in all calculations.

TABLE 7

ESTIMATES OF AVERAGE DIAMETER
BY DIAMETER CLASS OF PIECES

Diameter class (cm)	(Average diameter) ² (cm ²)
0-0.64	0.0445
0.64-2.54	1.6129
2.54-7.62	17.9213

For pieces of more than 7.62 cm, the real diameters were recorded. The sum of square diameters then replaces πd^2 in the formula (7). In calculating the weight or the volume of this class a distinction between the green and decayed pieces must be made.

3.0 RESULTS

3.1 Weighing Method

Table 8 shows green and oven-dry weights of residues in a lodge-pole pine stand. They are respectively 49.80 t/ha and 34.25 ODt/ha.

Figure 2 shows the cumulative distribution of these results.

In Table 9 quotients and moisture contents, expressed on a green and oven-dry basis, for each class of residues are given.

The ratio is defined as the oven-dry weight over the green weight. The weighted ratio, based on total residues, is 0.68686. The corresponding moisture contents, on green and oven-dry basis, are respectively 31.314% and 45.590%.

Tables 10 and 11 show statistics on stumps and residual trees.

An average of 911 stumps/hectare was recorded. The average diameter and the total volume, of those stumps were 9.62 cm and 3.53 m³/ha. The average volume was 3.87 dm³. Finally, 16.46% of the stumps had a diameter smaller than 7.6 cm.

The number of residual trees averaged 11.54 per hectare. These trees generally measure 2.54 cm in diameter and 2.05 m in height for a volume of 0.012 m³/ha, and the average volume per residual tree was 1.04 dm³.

TABLE 8
GREEN AND OVEN-DRY WEIGHTS OF
LODGEPOLE PINE RESIDUES
(WEIGHING METHOD)

Category of residues	(Weight (t/ha))	
	wet	oven-dry
Tops	9.42	6.55
Branches	21.04	14.85
Green stems	6.70	4.78
Dead stems	11.29	7.11
SUB-TOTAL	48.45	33.29
Stumps	1.34	0.96
Residual trees	0.01	0.00*
TOTAL	49.80	34.25

* negligible quantity

FIGURE 2

CUMULATIVE WEIGHTS OF RESIDUES
Lodgepole pine - weighing method

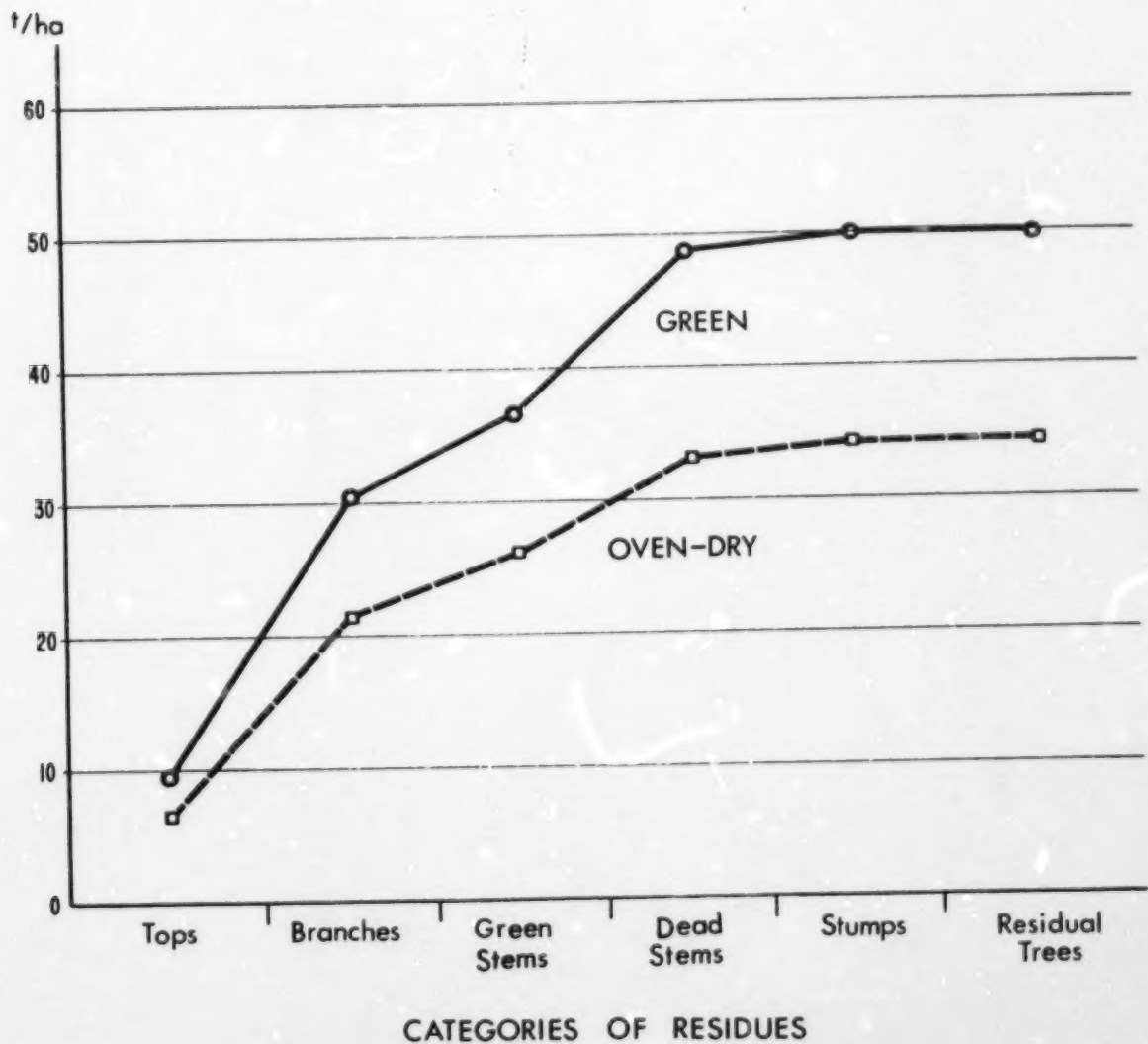


TABLE 9 RATIOS AND MOISTURE CONTENT OF LODGEPOLE PINE RESIDUES
(WEIGHING METHOD)

Categories of Residues	RATIOS*		% moisture	
	A/H		(H-A)/H	
Tops	0.69429		30.571	44.033
Branches	0.70565		29.435	41.713
Green stems	0.71396		28.604	40.065
Dead stems	0.62954		37.046	58.847
TOTAL	0.68686*		31.314	45.590

H = green

A = oven-dry

* weighted ratio = $\frac{\sum \text{all classes of oven-dry residues}}{\sum \text{all classes of green residues}}$

TABLE 10
STATISTICS ON STUMPS

	<u>Minimum</u>	<u>Maximum</u>	<u>Average</u>
Number/ha	494	1631	911
Volume (m ³ /ha)	1.739	5.601	3.530
Diameter (cm)	2.5	53.3	9.62
Average stump volume (dm ³)			3.87
% < 7.6 cm			16.46

TABLE 11
STATISTICS ON RESIDUAL TREES

	<u>Minimum</u>	<u>Maximum</u>	<u>Average</u>
Number/ha	0	148.26	11.54
Volume (m ³ /ha)	0	0.15	0.012
Diameter (cm)	2.54	2.54	2.54
Height (m)	1.65	2.59	2.05
Average residual tree volume (dm ³)			1.04

3.2 Transect Method

Table 12 shows the proportion of intersections by diameter class of residues and by species for the lodgepole pine stand.

Of 8326 pieces recorded, 7889 were classified as sound and 437 as decayed. The 0-0.63 cm class was the most important in number of pieces. In fact, 64.16% of the pieces belonged to that class. The 0.64-2.53 cm class was second in the proportion of pieces counted with 21.30%.

In order of importance the observed species were lodgepole pine, white spruce, and alpine fir with 73.03%, 14.47% and 12.50% of the number of intersections respectively.

Table 13 presents the number of pieces counted in the following categories: tops, branches, blown down trees, broken stems, stumps, and roots.

The majority of pieces counted were classified as tops and branches (84.66%), broken trunks (6.67%) and roots (6.43%).

From the number of intersections it was possible to calculate the weight and the volume of the pieces. The average green weight of the pine stand residues was 47.68 t/ha with a corresponding volume of 124.98 m³/ha. (Table 14)

Table 15 shows the result of the inventory in the white spruce stand.

Of the 12,684 pieces counted, 11,789 were sound and 895 were decayed. The most important diameter classes in number of pieces were the 0-0.63 cm class (65.62%), 0.64-2.53 (18.82%) and 7.62 cm plus (10.34%).

In Table 16 nearly 96% of the pieces were classified as tops and branches (85.46%) and green stems (10.30%).

The average green weight and volume of residue in the white spruce stand were 63.73 t/ha and 167.29 m³/ha respectively. (Table 17)

Table 18 shows the ratios and the moisture contents of lodgepole pine and white spruce residues by diameter class.

Applying the ratios to the green weight gave the oven-dry weight of the residues. It was found that lodgepole pine and white spruce had average oven-dry weights of 32.21 ODt/ha and 40.93 ODt/ha respectively. (Table 19)

Figure 3 shows the cumulative distribution of residues in the pine stand inventories by the transect method.

Figure 4 gives the same information for the spruce stand. Green and oven-dry weights are given in both of these figures.

TABLE 12

PROPORTION OF INTERSECTIONS BY DIAMETER
CLASS AND BY SPECIES
(LODGEPOLE PINE)

Diameter Class (cm)	Intersections				
	Sound	Number Decayed	% Class	Presence % per class	
				Alpine fir	Lodgepole Pine
0.00 - 0.63	5293	49	64.16	15.28	66.40
0.64 - 2.53	1725	51	21.30	8.90	81.48
2.54 - 7.61	475	83	6.70	3.94	90.68
7.62+	399	254	7.84	6.89	88.97
SUB-TOTAL	7889	437	100.00	12.50	73.03
TOTAL		8326	100.00		100.00



Photo no. 1: Illustration of a study plot and general view of the area.



Photo no. 2: Illustration of the
weighing device with
a load of branches.

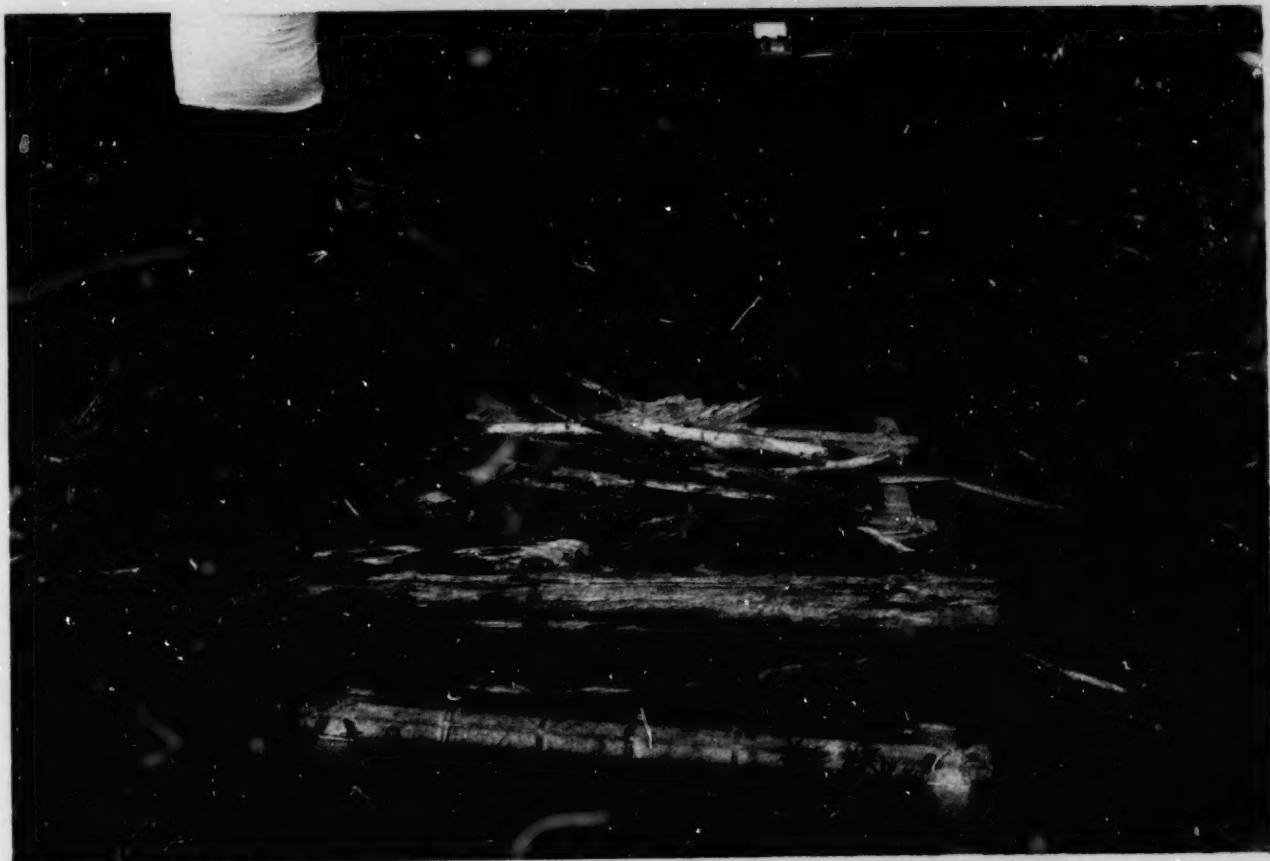


Photo no. 3: Preparation for
weighing dead
wood (trunks).



Photo no. 4: Illustration of different samples for determination of oven-dry weight and moisture content.

TABLE 13
PROPORTION OF INTERSECTIONS BY DIAMETER CLASS
AND BY CATEGORY OF RESIDUES
(LODGEPOLE PINE)

Diameter class (cm)	Categories of residues			
	<u>Tops and branches</u>	<u>Blown down trees</u>	<u>Broken stems</u>	<u>Stumps</u> <u>Roots</u>
0.00 - 0.63	91.37	0.28	0.41	0.04 7.90
0.64 - 2.53	93.64	0.79	3.21	- 2.36
2.54 - 7.61	76.88	10.76	8.06	0.72 3.58
7.62 +	11.79	2.76	66.31	11.49 7.65
SUB TOTAL	84.66	1.27	6.67	0.97 6.43
TOTAL			100.00	

TABLE 14 GREEN WEIGHT AND VOLUME OF LODGEPOLE PINE
RESIDUES BY THE TRANSECT METHOD

Diameter (cm)	Greenweight (t/ha)		Volume (m ³ /ha)	
	<u>Total</u>	<u>Average</u>	<u>Total</u>	<u>Average</u>
0.00 - 0.63	100.81	0.58	210.10	1.21
0.64 - 2.53	508.91	2.94	1060.68	6.13
2.54 - 7.61	462.91	2.67	883.77	5.11
7.62 + (sound)	3583.56	20.71	9360.40	54.11
7.62 + (decayed)	3596.25	20.78	10105.93	58.42
TOTAL	8252.44	47.68	21620.88	124.98

TABLE 15
PROPORTION OF INTERSECTIONS BY
DIAMETER CLASS AND BY SPECIES
(WHITE SPRUCE)

Diameter class (cm)	Intersections				
	Number		%	% in class	
	Sound	Decayed		Alpine fir	Lodgepole pine
0.00 - 0.63	8229	94	65.62	31.25	2.44
0.64 - 2.53	2274	113	18.82	31.46	6.20
2.54 - 7.61	507	155	5.22	28.40	7.25
7.62 +	779	533	10.34	30.49	7.09
SUB-TOTAL	11789	895	100.00	31.06	3.88
TOTAL	12684		100.00		100.00

66.31

62.34

64.35

62.42

65.06

TABLE 16
PROPORTION OF INTERSECTIONS BY DIAMETER CLASS
AND BY CATEGORY OF RESIDUES
(WHITE SPRUCE)

Diameter class (cm)	Tops and branches	Categories of residues			Roots
		Blown down trees	Broken stems	Stumps	
0.00 - 0.63	95.77	0.13	1.12	-	2.98
0.64 - 2.53	94.52	0.08	3.35	-	2.05
2.54 - 7.61	75.83	0.45	19.34	0.30	4.08
7.62 +	8.46	2.21	76.61	7.16	5.56
SUB-TOTAL	85.46	0.35	10.30	0.76	3.13
TOTAL			100.00		

TABLE 17
GREEN WEIGHT AND VOLUME OF WHITE SPRUCE RESIDUES
(TRANSECT METHOD)

Diameter (cm)	Green weight (t/ha)		Volume (m ³ /ha)	
	<u>Total</u>	<u>Average</u>	<u>Total</u>	<u>Average</u>
0.00 - 0.63	173.40	1.01	361.28	2.10
0.64 - 2.53	732.48	4.26	1526.62	8.88
2.54 - 7.61	503.53	2.94	1053.83	6.13
7.62 + (sound)	5580.58	32.44	12630.89	73.43
7.62 + (decayed)	3971.87	23.09	13201.13	76.75
TOTAL	10961.86	63.73	28773.75	167.29

TABLE 18 RATIOS AND MOISTURE CONTENT OF WHITE SPRUCE AND LODGEPOLE PINE RESIDUES
(TRANSECT METHOD)

Diameter (cm)	Ratio * A/H		% moisture (H-A) / H		% moisture (H-A) / H	
	<u>Pine</u>	<u>Spruce</u>	<u>Pine</u>	<u>Spruce</u>	<u>Pine</u>	<u>Spruce</u>
0.00 - 0.63						
0.64 - 2.53	0.70565	0.65139	29.435	34.861	41.713	53.518
2.54 - 7.61	0.69429	0.64451	30.571	35.549	44.033	55.156
7.62 + (sound)	0.71396	0.67027	28.604	32.973	40.065	49.194
7.62 + (decayed)	0.62954	0.60115	37.046	39.885	58.847	66.348

* weighted ratio = $\frac{\sum \text{all classes of oven-dry residues}}{\sum \text{all classes of wet residues}}$

TABLE 19 OVEN-DRY WEIGHT OF LODGEPOLE PINE AND WHITE SPRUCE RESIDUES
(TRANSECT METHOD)

Diameter (cm)	Oven-dry weight (ODt/ha)			
	Lodgepole pine		White spruce	
	<u>Total</u>	<u>Average</u>	<u>Total</u>	<u>Average</u>
0.00 - 0.63	71.15	0.40	113.03	0.65
0.64 - 2.53	358.49	2.06	447.19	2.78
2.54 - 7.61	320.41	1.86	325.54	1.88
7.62 + (sound)	2558.41	14.80	3739.58	21.74
7.62 + (decayed)	2263.22	13.09	2387.41	13.88
TOTAL	5571.68	32.21	7042.76	40.93

FIGURE 3

CUMULATIVE WEIGHT OF RESIDUES

Lodgepole pine - transect method

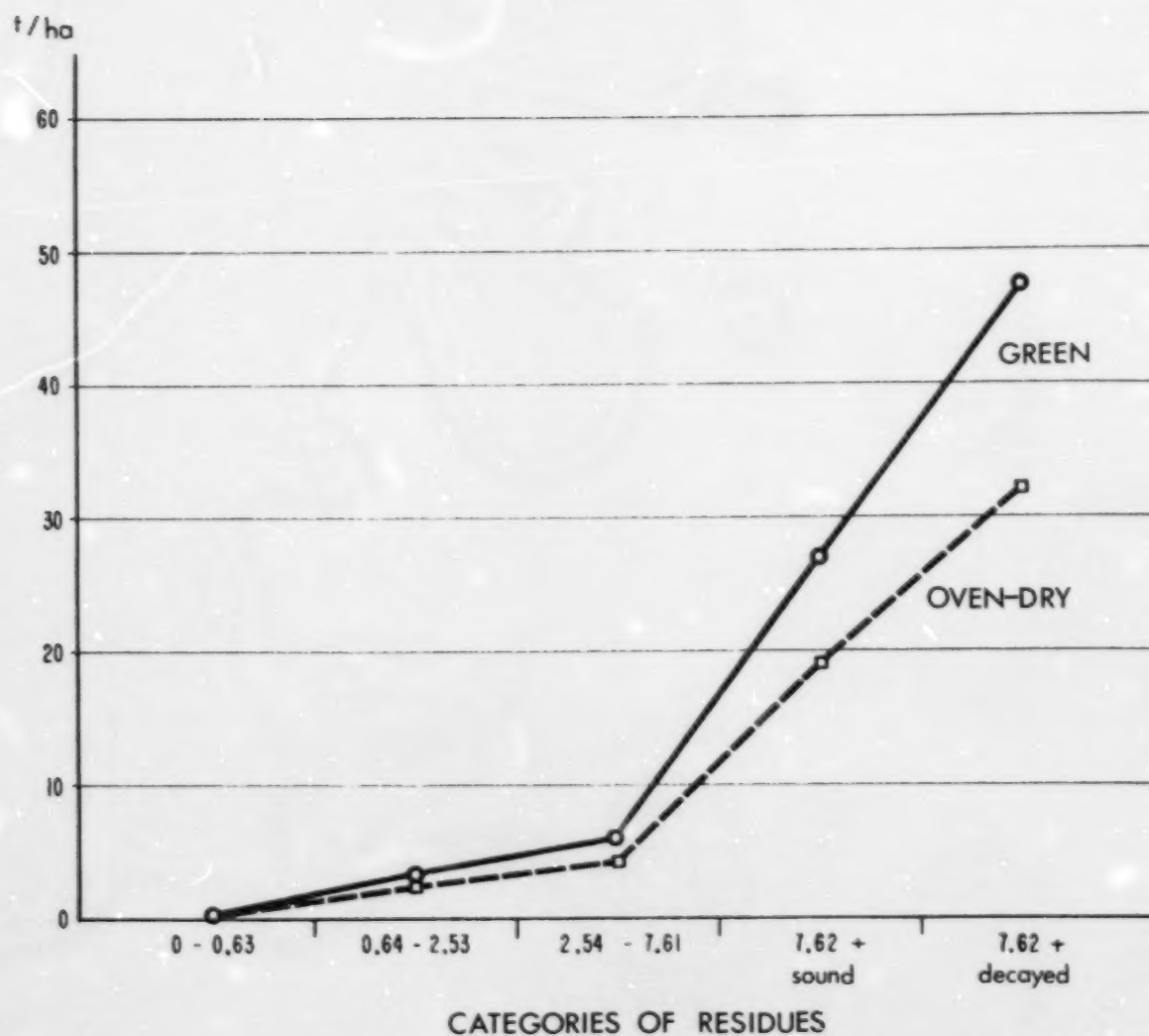
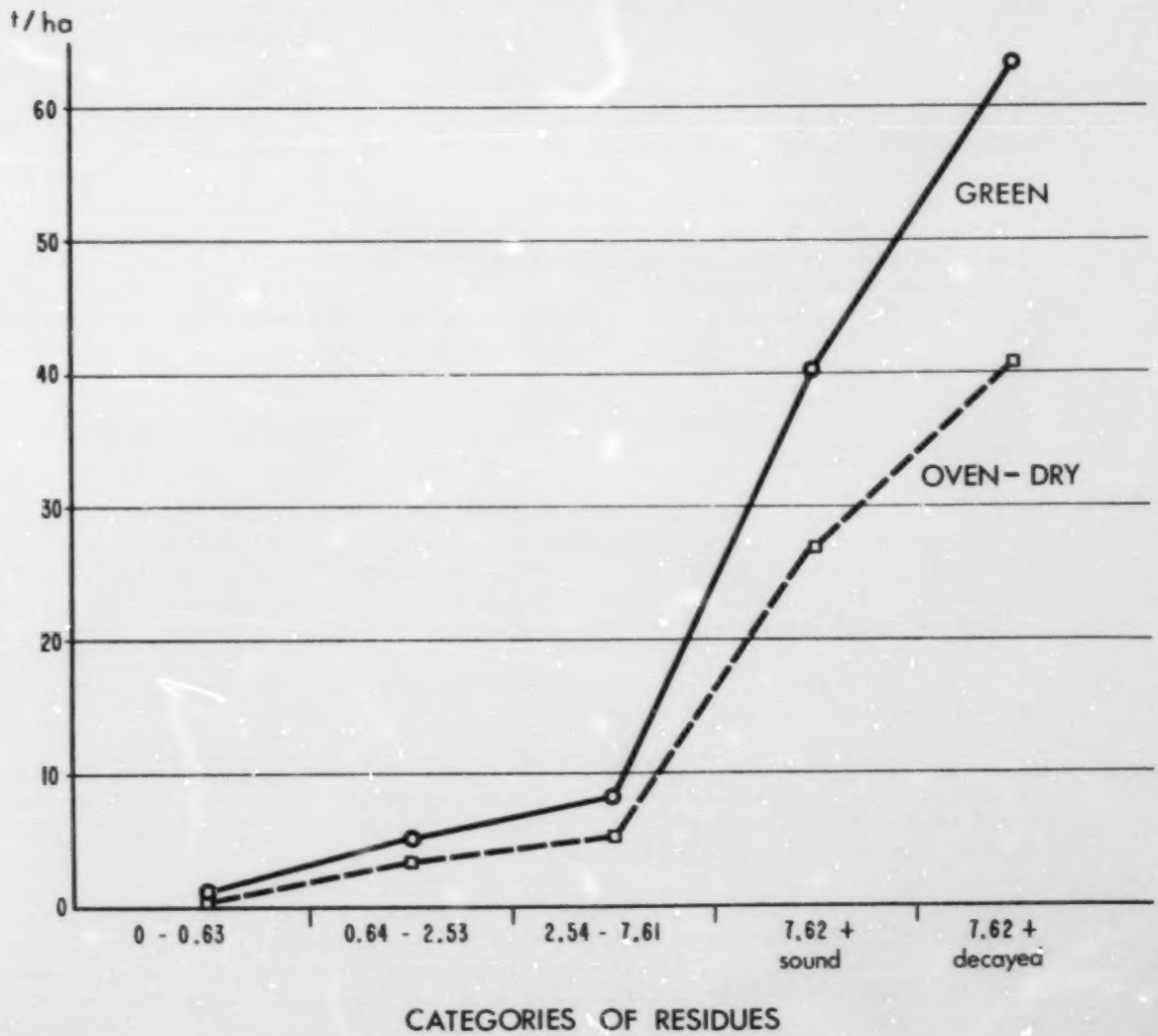


FIGURE 4

CUMULATIVE WEIGHT OF RESIDUES

White spruce - transect method



As mentioned earlier, separate samples were taken for the specific gravity of residues by diameter class. These values appear in Table 20. On the average the specific gravity of pine and spruce were similar, i.e. 0.382 and 0.381.

Table 21 shows the weight that would have been obtained with the specific gravity values given in existing tables. In fact they are theoretical values originating from reports of reference manuals. The average green weight of the pine stand residue would be 44.72 t/ha, whereas the spruce stand weight would be 60.09 t/ha.

3.3 Comparative Analysis

Table 22 shows interesting statistics on minimum and maximum green and oven-dry weights calculated for all sampling units and the estimated weight, for every species, in each of the inventory methods used. Finally, it gives minimum, maximum, and average volumes.

Figure 5 shows the percentage error in estimating the average weight in relation to the number of sample plots. It also gives a mathematical equation of the form $Y = a + bx$ for estimating the error.

The percentages of error found in the results of the inventory were lower than the maximum tolerance. In the case of the pine forest, where the results were obtained by using the weighing methods and 15 sample plots, the error was 11.06%. By using transects, in the same forest type, the error was 14.09% with 173 plots. Finally, for the spruce type, where the results were obtained by using the transect method on 172 plots, the error was 9.26%.

The R^2 coefficients for the above calculation are 0.89510, 0.82475 and 0.81842.

Table 23 compares the different weights obtained. With reference to the green weight obtained by the weighing method, the relative error attributed to the transect method could be either (-)4.26% or (-)10.20% depending on the use of specific gravity values, either measured in the laboratory (transect 1) or taken from existing tables (transect 2).

With reference to the oven-dry weight (weighing method), the errors are (-)5.96% and (-)11.80%.

If comparisons are made with reference to the green weight result of transect (1), the estimation of the green weight from the weighing method would be overestimated by 4.45%, whereas it would be underestimated by 6.21% if the transect (2) method was used.

If comparisons are made with reference to the oven-dry weight of transect (1), the weighing method would give a difference of (+)6.33%, whereas transect (2) would evidently remain at (-)6.21%. It is to be noted, that only lodgepole pine residues are used in comparing weight and transect methods.

TABLE 20
SPECIFIC GRAVITY MEASURED IN THE LABORATORY

<u>Diameter class (cm)</u>	<u>Lodgepole pine</u>	<u>White spruce</u>
0.00 - 2.53 (1)	0.480	0.480
2.54 - 7.61	0.523	0.478
7.62 + (sound)	0.383	0.442
7.62 + (decayed)	0.356	0.301
TOTAL	0.382	0.381

(1) Values of 0.48 were not derived from laboratory measurements.

TABLE 21 GREEN WEIGHT ESTIMATED FROM SPECIFIC GRAVITY TAKEN FROM TABLES

Diameter class (cm)	Lodgepole pine		White spruce	
	s (1)	Weight (t/ha)	s (1)	Weight (t/ha)
0.00 - 2.53	0.48	3.52	0.48	5.27
2.54 - 7.61	0.40	2.04	0.40	2.45
7.62 + (sound)	0.40	21.63	0.40	29.36
7.62 + (decayed)	0.30	17.52	0.30	23.02
TOTAL		44.72		60.09

(1) Average values for softwoods, suggested by J.K. Brown.

TABLE 22 STATISTICS ON TOTAL RESIDUES OF LODGEPOLE PINE AND OF WHITE SPRUCE,
USING BOTH SAMPLING METHODS

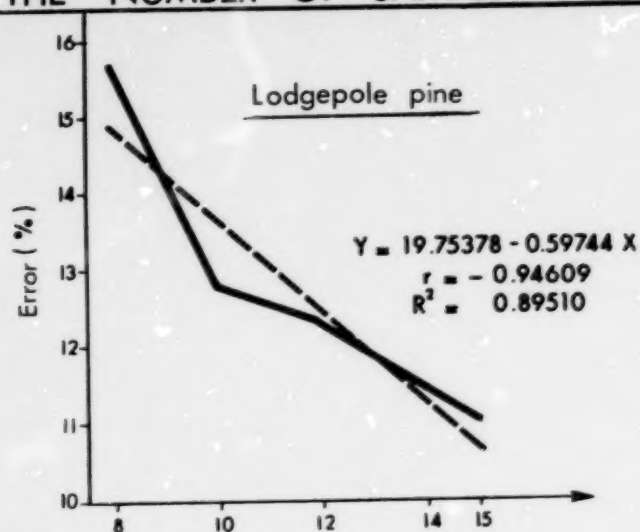
		Weight (t/ha)			Volume (m ³ /ha)		
		MIN.	MAX.	AVG.	MIN.	MAX.	AVG.
Lodgepole pine	(H)	33.90	62.65	49.80	89.20	164.87	130.48
Weighing	(A)	23.28	43.03	34.25			
Lodgepole pine	(H)	5.60	286.27	47.68	13.30	776.35	124.98
Transect	(A)	3.78	193.68	32.21			
White spruce	(H)	5.76	238.43	63.73	12.66	542.71	167.29
Transect	(A)	3.70	153.13	40.93			

H: Green

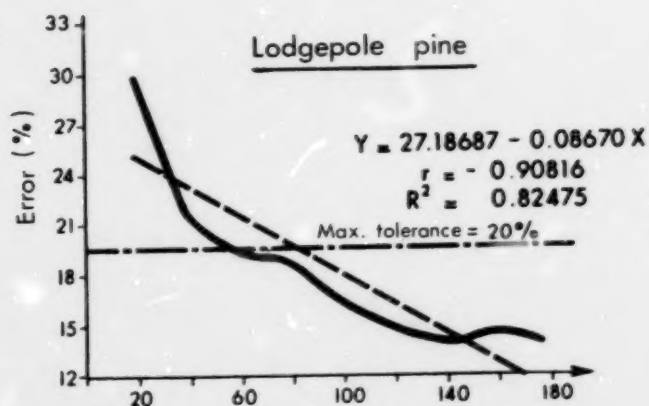
A: Oven-dry

VARIATION OF ERROR IN TOTAL RESIDUES ESTIMATE VS. THE NUMBER OF SAMPLE PLOTS

Weighing



Transect



Transect

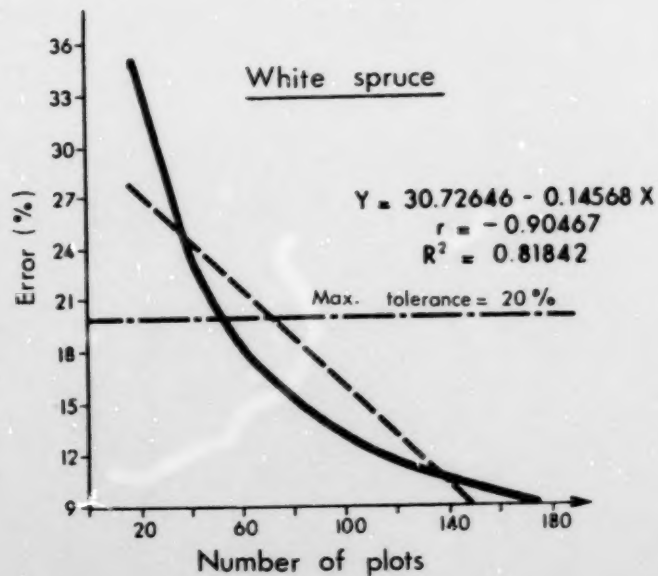


TABLE 23 COMPARISON OF THE RESULTS OBTAINED FROM
DIFFERENT SPECIFIC GRAVITIES
(LABORATORY VS THEORETICAL VALUES)

Species and method	Weight (t/ha)		Relative error (%)			
	Green	Oven-dry	Green	Weighing Oven-dry	Green	Transect (1) Oven-dry
Lodgepole pine Weighing	49.80	34.25	—	—	4.45	6.33
Lodgepole pine Transect (1)	47.68	32.21	-4.26	-5.96	—	—
Lodgepole pine Transect (2)	44.72	30.21	-10.20	-11.80	-6.21	-6.21
White spruce Transect (1)	63.73	40.93	—	—	—	—
White spruce Transect (2)	60.09	38.59	—	—	-5.71	-5.71

Transect (1): weights estimated from laboratory analyses
Transect (2): weights estimated from theoretical values (Brown)

In the spruce stand it was noted that the transect (2) result was under-estimated by 5.71% compared with transect (1).

Finally, Figure 6 illustrates, in percentages of total weight, the distribution of residues for two species and for the two inventory methods used.

4.0 DISCUSSION OF THE RESULTS

4.1 Weighing Method

It is shown that 62.8% of the green weight of logging residues, i.e. tops; branches; green or dead stems, is made up of tops and branches (Table 8).

This indicates clearly that the stand was logged by tree length. Yet, the first impressions were of full tree logging because of the small volume of residues. There were a few scattered concentrations but no uniform and thick accumulations as was observed in balsam fir and black spruce stands in a study made earlier in Eastern Canada.

The results from the pine stands in this study compared surprisingly well with those from full tree logging of jack pine. The inventory gave 32.9 ODt/ha against 34.25 ODt/ha for lodgepole pine cut in tree lengths.

It was the first time, in all our slash inventories, that such a clean logging operation was encountered. Delimbing and topping operations were very well performed. No long or big tops were left on the ground. It seemed that there were fewer residual standing trees. This explains the lower volume of logging residues.

4.2 The Transect Method

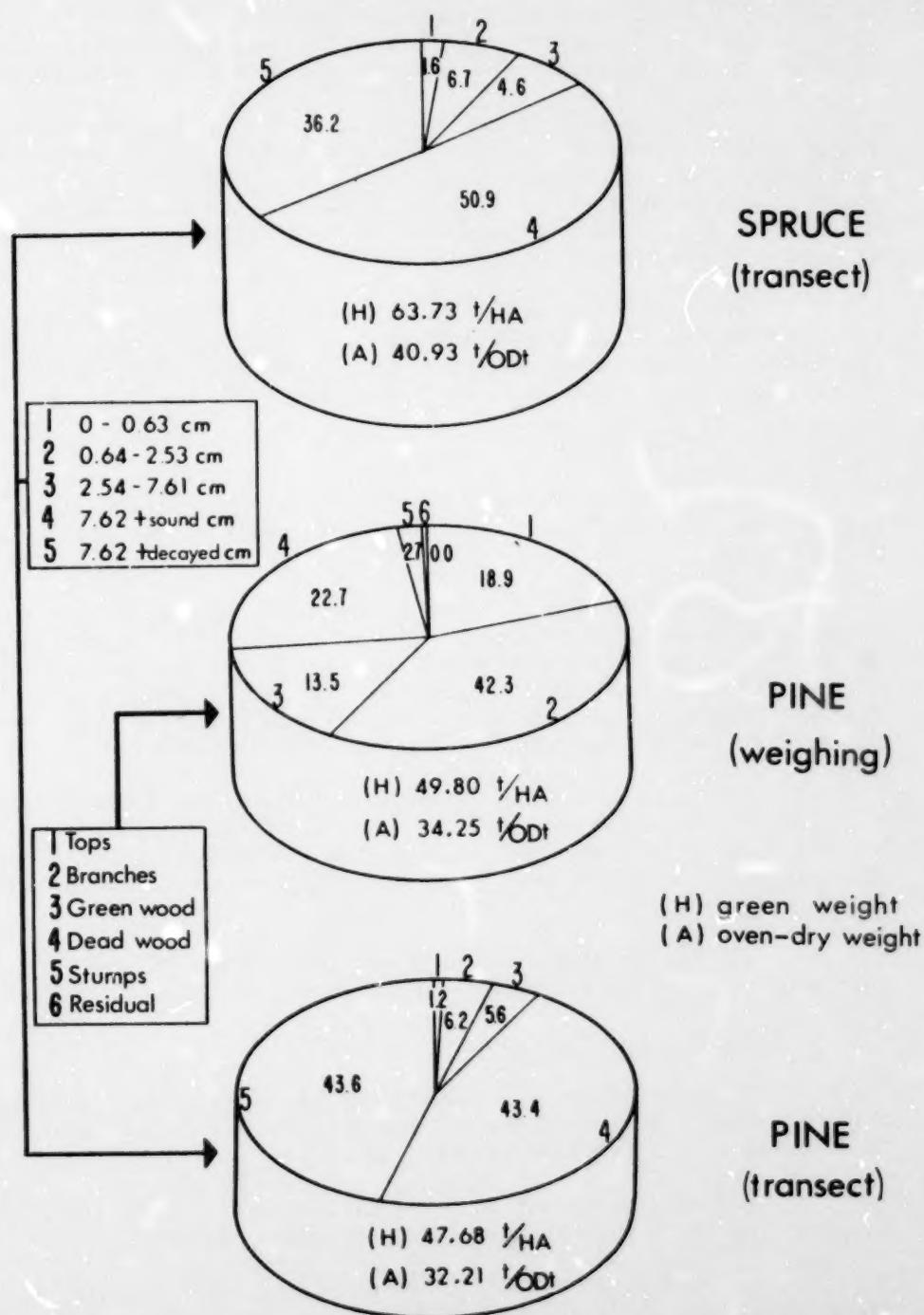
4.2.1 Importance of Sampling

Referring to the values of lodgepole pine residues in tables 12, 13 and 14, it is seen that 85.46% of the number of intersections were smaller than 2.54 cm; that tops and branches accounted for 84.66% but their green weight was equivalent to only 7.38% of the total weight. Pieces larger than 7.62 cm represented only 7.84% of the total number of counted pieces, but their weight was 87.02% of the total residues.

The same trend can be seen for the values of white spruce residues in tables 15, 16 and 17: up to 84.44% of the number of intersections were under 2.54 cm; tops and branches represented 85.46%, but their weight was no more than 8.27% of the total weight of residues. Pieces of more than 7.62 cm, with only 10.34% of the total number, accounted for 87.13% of the total green weight.

In light of these results it is evident that the weight of residues per diameter class was inversely proportional to the number of intersections recorded.

DISTRIBUTION OF RESIDUES AS A % OF TOTAL WEIGHT



Inappropriate sampling intensity, or insufficient number of sample plots, may produce false results. Hence, it is very important to determine these parameters at the beginning. This requires a knowledge of the conditions of the working area, namely the degree of uniformity of the residue cover as well as its depth. If the residues are scattered, corrective measures should be taken to increase their probability of being counted.

Accordingly it is believed that the method of orienting the sampling units proposed by J.O. Howard and F.R. Ward (1972) might be more appropriate than the Brown method. Instead of directing the lines of sampling always between 0° and 150°, or always to the right of the transect, it could be done between 0° and 330°, i.e. a full rotation but with line direction always determined at random.

This method of orienting the sampling lines has produced better results than the following two methods: 1) the sampling lines always in the same direction as the transect, and 2) perpendicular (L-shape) sampling lines always in the same direction (Ref. Ward and Howard study).

4.2.2 Ratios

Referring to tables 9 and 18, it is apparent that ratios for pine are the same for both methods. This is because the same samples were used in both cases.

After selecting the samples according to the categories of the weighing method they were theoretically distributed by diameter classes, on the assumption that the branches were under 2.54 cm and the tops were between 2.54 and 7.61 cm. The 7.62+ cm class was divided into two subclasses: the round residue subclass, which included the green stems; and the decayed residue subclass, consisting of the dead stems.

The results obtained by this method are not quite exact. In fact, the weighted ratio is 0.68686 for the weighing method, and 0.67555 for the transect method. The average oven-dry weight for the lodgepole pine residues, by the transect method, should be 32,75 ODt/ha instead of 32.21 ODt/ha.

The slight difference between ratios might be due to the fact that some samples did not belong to the designated class.

4.2.3 Specific Gravity

The accuracy of the results can be influenced considerably by this parameter. Tables 20 and 21 show calculated specific gravities and those taken from scientific reports, respectively.

However, as mentioned earlier, the specific gravity of the pieces in class 0-2.53 cm was not calculated in the laboratory.

In classes 2.54-7.61, 7.62+ sound and 7.62+ decayed, the differences are respectively (-)23.5%, (+)4.4% and (-)15.7% for lodgepole pine (differences found in relation to calculated values). For white spruce the differences in the same classes are (-)16.3%, (-)9.5% and (-)0.3%.

Of the six results four were under-estimated, one was over-estimated, and one was practically identical.

Therefore, it is of prime importance to establish these values precisely, and to use the laboratory values for best results.

4.3 Comparative Analysis

Table 23 shows a difference of (-)4.26% between the two methods of inventory, with respect to the weighing method. When the ratio is applied to the transect method, as explained earlier, the relative error, as to the oven-dry weight, goes up to (-)5.96%.

Applying the effect of theoretical specific gravity values to these figures, the relative error due to the method used goes from (-)4.26% to (-)10.20%. Introducing the ratio again, the relative error increases from (-)5.96% to (-)11.80%.

Comparisons are made in relation to the weighing method. The reference total weight is 49.80 t/ha (green). This total includes stumps (1.34 t/ha) and residual trees (0.01 t/ha).

It is not possible to obtain these results with the transect method (stumps and residual trees) without an additional inventory.

Therefore, the results obtained with the transect method will be compared with the total weight of residues, which can be classed as logging residues, i.e. tops, branches, green and dead wood stems. (Table 24)

The weighed ratio as calculated for the weighing method was used to adjust the results of the transect method. The oven-dry weight/green weight coefficient is the same for all the results in this table. The differences result only from the various methods and to the variation in the specific gravity.

The relative error due to the sampling method is now reduced to (-)1.59% as compared with (-)4.26% previously. The use of specific gravity increases this difference to (-)7.70% (previously -10.20%).

It can also be seen that the alternate ways of obtaining the specific gravity values make a (-)6.21% difference in the results of the transect method.

4.4 Accuracy of the Methods

Figure 5 indicates that, for a given level of dependability, the number of sample plots can vary considerably.

With 15 sampling units, the weight method is 89% exact, while as many as 173 sampling lines in the same forest stand are necessary to obtain an 86% precision level with the transect method. As for the white spruce stand, 172 sample plots gave a precision level of 91%.

TABLE 24 COMPARISON OF THE LOGGING RESIDUE*CONSIDERING THE
VARIATION OF WEIGHTED RATIOS

Species and method	Weight (t/ha)		Relative error (%)			
	Green	Oven dry	Weighing		Transect (1)	
			Green	Oven dry	Green	Oven dry
Lodgepole pine	48.45	33.29	-	-	+1.61	+1.65
Weighing						
Lodgepole pine	47.68	32.75	-1.59	-1.62	-	-
Transect (1)						
Lodgepole pine	44.72	30.72	-7.70	-7.72	-6.21	-6.20
Transect (2)						

* Logging residue = $\bar{x}$ residue - (stumps + residual trees)

One must remember that sampling was intensified by using longer lines in certain classes of residues.

The difference in the number of sample plots recorded per size class can be readily understood by considering the minimum and maximum values in Table 22. As the range widens the variance increases and, accordingly, the number of sampling units must be increased in order to maintain the required precision.

Hence, with the weighing method, the difference between minimum and maximum is only 30 t/ha (green) approximately, whereas it reaches 280 t/ha and 230 t/ha for pine and spruce respectively by the transect method.

There are, however, serious doubts concerning the applicability of the transect technique with large amounts of residue. It is possible to shorten the length of the sampling lines, but this is not the major difficulty. It is felt that counting would become more difficult and would require greater attention on the researchers' part. There would thus be a higher risk of mental fatigue and error.

Furthermore, one of the basic principles of the transect technique requires absolutely no movement of the pieces on the ground. However, this condition makes it practically impossible to place the sampling line on the ground and to lay out the tape.

Brown suggests a rather special technique (Jacob's staff) which introduces the sampling method called "3P". A relationship is established between ocular estimates and the number of pieces counted. Still, difficulties of a practical nature persist with this sub-sampling technique in conditions such as those found in a previous inventory, especially in black spruce, fir, or even maple stands, where the residues were sometimes waist high or higher.

CONCLUSION

From this study, it would appear that the weighing method and the transect technique produce similar results. For lodgepole pine the average green weights are 49.80 t/ha (weight) and 47.68 t/ha (transect). For white spruce the average green weight is 63.73 t/ha (transect only).

However, it should be noted that the inventorying conditions, accumulation, and spread of the residues, were almost ideal.

Some important points require special attention when using the transect technique:

- appropriate sampling intensity: a sufficiently large number of sampling lines of adequate length, depending on the quantity of residues, is essential.

- direction of the sampling planes: it would probably be more appropriate to adopt a pattern allowing a distribution of the sampling lines over 360° , thus increasing the probability of the larger pieces being counted.
- determination of specific gravity: it would be preferable to calculate the specific gravity values in a laboratory, by diameter class and by species, in order to improve accuracy because the error in weight calculations, attributable to this factor, can be as high as 10%.
- determination of ratios by diameter class: this would give a slight improvement in accuracy compared with the weighted ratios obtained from the usual weighing method categories.

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APPENDIX 1 Meteorological data from Obed station. White spruce

DATE JULY	TEMPERATURE °C		RELATIVE HUMIDITY	WIND VELOCITY (km/h)	RAINFALL mm
	MAXIMUM	MINIMUM			
1	14.5	7.5	45	16	
2	18.0	10.5	40	15	
3	20.5	10.5	57	8	
4	17.0	8.0	63	16	3.4
5	16.0	4.0	70	12	2.6
6	12.0	3.0	100	25	4.3
7	13.0	3.0	58	9	
8	19.5	10.0	49	11	
9	19.5	10.0	55	17	
10	22.5	8.0	66	14	1.0
11	16.5	5.5	88	17	10.2
12	11.5	4.5	76	8	0.5
13	18.0	9.0	62	12	
14	17.0	8.5	89	13	3.1
15	13.5	7.5	63	21	2.8
16	15.0	4.5	79	13	
17	11.0	4.0	100	13	5.2
18	9.0	4.0	97	7	4.2
19	10.0	2.0	91	3	24.5
20	13.5	6.5	64	19	
21	18.5	10.5	62	2	
22	20.0	12.5	72	20	
23	21.5	7.5	55	32	9.7
24	17.0	5.0	52	5	
25	16.5	7.5	69	14	
26	17.0	8.0	60	8	
27	15.0	6.5	58	12	
28	17.0	6.0	73	16	10.8
29	15.5	4.5	53	15	
30	16.0	6.0	52	4	
31	17.0	8.5	52	12	
TOTAL RAINFALL 82.3					
Average Temperature					
Maximum		Minimum	Average relative humidity	Average wind velocity	Average rainfall
16.1		6.9			
			66.8	12.9	2.7

APPENDIX 2 Meteorological data from Athabaska station.
Lodgepole pine and white spruce

DATE JULY	TEMPERATURE A.M. °C		RELATIVE HUMIDITY	WIND VELOCITY (km/h)	RAINFALL (mm)
	MAXIMUM	MINIMUM			
1	15	8	58	15	
2	20	11	42	14	
3	21	12	52	3	
4	19	9	56	16	1.4
5	17	4	56	16	0.8
6	13	4	82	17	1.0
7	12	7	60	15	
8	20	11	45	14	
9	22	10	51	17	
10	22	9	69	7	
11	11	6	94	10	11.5
12	10	6	77	6	6.9
13	17	11	62	17	
14	18	10	71	12	0.3
15	16	8	67	13	3.9
16	15	5	77	9	0.3
17	14	5	88	6	2.3
18	11	5	95	8	4.8
19	11	3	87	6	32.9
20	15	8	60	15	
21	19	12	64	11	
22	22	13	66	13	
23	23	10	54	16	1.3
24	18	7	57	5	
25	16	9	73	12	0.1
26	18	10	53	3	
27	16	8	58	6	
28	19	7	80	14	6.3
29	16	6	51	10	TOTAL RAINFALL 67.5 mm
30	17	8	58	3	
31	18	9	54	18	
	Average temperature		Average relative humidity	Average wind velocity	Average rainfall
	Maximum	Minimum			
	16.8	8.1			